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X-ray sources in Galactic old open star clusters

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Abstract. I review the current status of studies of the X-ray sources in Galactic old open clusters. Cataclysmic variables (CVs), magnetically-active binaries (ABs), and sub-subgiants (SSGs) dominate the X-ray emission of old open clusters. Surprisingly, the number of ABs detected inside the half-mass radius with $L_X \gtrsim 1 \times 10^{30}$ erg s^{-1} (0.3–7 keV) does not appear to scale with cluster mass. Comparison of the numbers of CVs, ABs, and SSGs per unit mass in old open and globular clusters shows that each of these classes is under-abundant in globulars. This suggests that dense environments suppress the frequency of even some of the hardest binaries.

1. Introduction

The fate of star clusters and the binaries in them are closely intertwined. Dynamical encounters between single stars and binaries affect the stellar velocity distribution, and thus the evolution of the cluster as a whole; vice versa, the dense environment of a cluster can trigger interactions that affect the binary properties. Open clusters allow detailed studies of complete samples of binaries, with the advantage that their age, distance, and composition are known from cluster membership. Surveys like the WIYN Open Cluster Study (Mathieu 2000) now enable a detailed comparison between observations and numerical models of the evolution of stellar clusters and their binary populations (e.g. Hurley et al. 2005). Until the early 1990s, the study of old open clusters was not pursued with X-ray observations. The reason for this is that the expected contribution of single stars to the X-ray emission of old stellar populations is small. In low-mass stars X-rays are emitted by the hot gas of the corona surrounding the star. The level of X-ray emission is linked to the stellar rotation rate, as rotation powers the magnetic dynamo that is responsible for heating the corona; the lower the spin rate, the weaker the X-ray emission. The rotation of late-type single stars declines over time as a result of angular-momentum loss through wind outflows along the stars' magnetic field.

For stars that are part of a binary, a high level of X-ray emission can be maintained despite an advanced age. Systems in which mass is exchanged between the binary companions are bright in X-rays if one of the stars is a compact object. Examples are cataclysmic variables (CVs) where the compact star is a white dwarf, or low-mass X-ray binaries (LMXBs) that contain a neutron star or black hole. Strong tidal interaction between detached main-sequence stars in a close binary locks their rotation to the

orbital period. The rapid rotation induced by the synchronization keeps the dynamo active, and thus the process responsible for the X-ray production. Such systems are called magnetically-active binaries, or ABs in short. For a study of the interacting binaries in an old stellar population, X-ray emission is an excellent tracer.

X-ray observations are therefore crucial for studying how the environments of star clusters affect the binary numbers and binary properties. In this paper I review what we have learned from X-ray studies of old open clusters, a field to which Utrecht has contributed significantly. I start with an overview of X-ray studies of old open clusters in Sect. 2. In Sect. 3 I describe the various classes of open-cluster X-ray sources. Sect. 4 compares the X-ray properties of old open and globular clusters. The chapter by Frank Verbunt gives an overview of X-ray studies of globular clusters.

2. An overview of X-ray observations of old open clusters

2.1. *ROSAT*

The first old open cluster that was the target of a pointed X-ray observation is M 67 (NGC 2682). Belloni, Verbunt, and collaborators used the *ROSAT* Position Sensitive Proportional Counter (PSPC) to observe this 4-Gyr old cluster down to a limit of about 2×10^{30} erg s^{-1} (0.1–2.4 keV) in 1991. The photometric monitoring campaign by Gilliland et al. (1991), aimed at looking for solar-like oscillations in members of M 67, had just serendipitously discovered the first CV in an open cluster (EU Cnc). The light curve of this optically-faint object showed large-amplitude brightness variations at a period of 2.09 h that resembled the variability of so-called AM Her systems—CVs that contain a white dwarf with a strong magnetic field ($B \gtrsim$ 10 MG). The main motive for the X-ray observation by Belloni et al. was to do X-ray follow-up for this specific object; as CVs with accurate distance and reddening estimates were (and still are) rare, this was an excellent opportunity for an accurate measurement of the intrinsic X-ray luminosity (assuming cluster membership). The X-ray counterpart was readily detected, and the softness of its X-ray spectrum in the *ROSAT* band agreed with its AM Her classification (Belloni et al. 1993). Later, the magnetic nature was also confirmed by its optical spectrum (Pasquini et al. 1994) and *ROSAT* light curve (Belloni et al. 1998).

Although this initial observation of M 67 was not optimally pointed at the cluster center, it did reveal that at least six more likely members of M 67 were similarly bright in the *ROSAT* band as the CV. Thanks to the wealth of optical information available for this well-studied cluster, it quickly became clear that most of these (in fact: *all* of these, as we now know) are binaries with periods $\lesssim$45 d, including many with circular orbits. Since the theory of tidal interaction predicts that synchronization occurs before circularization (e.g. Zahn 1989), this suggests that in these systems the stellar rotation is coupled to the orbit. Belloni et al. (1993) therefore suggested that these sources are ABs in which the X-rays are the result of magnetic activity. A second *ROSAT* observation (this time centered on the cluster), combined with new optical results, detected many other binaries in M 67 and refined the classification of some of the earlier detections (Belloni et al. 1998). Surprisingly, this old cluster that at first seemed like an unexciting target for an X-ray study, revealed an enormous variety of X-ray sources. More details on the different source classes are given in Sect. 3.

Several other old open clusters, both younger and older than M 67, were studied with *ROSAT*. In order of increasing age, these are NGC 6940 (0.6–1 Gyr; Belloni & Tagliaferri

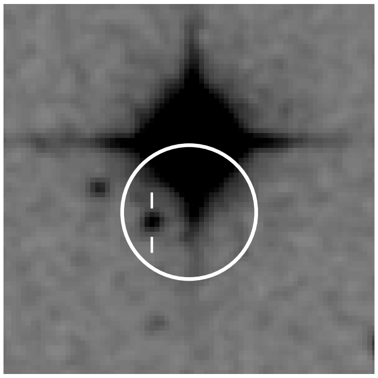

Figure 1 DSS image (1.25′ × 1.25′) around the source X 45 in NGC 752, illustrating the possibility for spurious identifications of *ROSAT* sources. The circle marks the 90% error radius. Belloni & Verbunt (1996) suggested that the wide binary and blue straggler H 209 (bright star) is the counterpart, but optical follow-up by van den Berg & Verbunt (2001) found no clues to the origin of the X-rays. An alternative $V \approx 18.9$ counterpart (vertical tick marks) is included in the GSC 2.3 catalog, but not in the GSC 1.0 catalog used for the optical identification.

1997), IC 4651 (1–1.5 Gyr; Belloni & Tagliaferri 1998), NGC 752 (2 Gyr; Belloni & Verbunt 1996), and NGC 188 (6.5 Gyr; Belloni et al. 1998). Classification of the X-ray sources in each of these resulted in a similar picture as for M 67: cross-correlation of the source lists with optical catalogs pointed at a high incidence of binaries among the candidate counterparts. An unexpected discovery was that some known binaries that were detected did not fit the profile of being circular, tidally-locked ABs. For example, some *ROSAT* sources were identified with eccentric systems having orbital periods of years, far too long for tidal coupling strong enough to induce rapid rotation. At present we still do not understand the X-rays of most of these long-period binaries (Sect. 3.4). Overviews of the *ROSAT* results can be found in Belloni (1997) and Verbunt (2000). None of the other clusters showed an X-ray source population so rich and varied as M 67. However, as M 67 was studied with the highest sensitivity (in part because of its proximity and low reddening) or with the largest fractional coverage, a systematic comparison between clusters based on the *ROSAT* data is difficult to make.

Positional uncertainties of the *ROSAT* sources range from about 5″ to 25″, and in some cases multiple candidate counterparts lie inside the error circles. By repeating their X-ray/optical matching with artificial source lists, Belloni et al. estimated that the chances for random coincidences were relatively small, and in fact many proposed identifications were later confirmed with *Chandra* or *XMM-Newton* observations. Indeed, the fraction of known binaries among the possible counterparts is too large to be entirely coincidental. On the other hand, in individual cases it is wise to be wary of the possibility of a spurious match. An example is the source X 45 in NGC 752, which Belloni & Verbunt (1996) identified with the blue straggler and long-period binary H 209 in NGC 752. This identification prompted a comparison with the detection of the blue straggler S 1082 in M 67, which was found to be a (possibly physically-bound) multiple system consisting of a long-period and short-period binary, in which the latter is responsible for the X-rays (see also Sect. 3.4). But extensive optical follow-up by van den Berg & Verbunt (2001) did not reveal any sign of a close binary in H 209. While it cannot be excluded that the parameters of H 209 are unfavorable for finding optical signatures for S 1082-like multiplicity, the option that the fainter optical source in the 90% error circle is the true counterpart should be seriously considered (Fig. 1). Low-resolution optical spectra are needed to classify this alternative counterpart; given

the $\sim 17''$-separation from the bright blue straggler, such spectra should be easy to acquire.

2.2. *Chandra* and *XMM-Newton*

With *Chandra* and *XMM-Newton* more sensitive studies have been done of clusters that had already been observed with *ROSAT*. van den Berg et al. (2004) describe a detailed *Chandra* study of M 67, NGC 188 was observed with *XMM-Newton* (Gondoin 2005), and a deep study of NGC 752 with both satellites—mainly aimed at studying the X-ray emission of single solar-type stars—can be found in Giardino et al. (2008). The sensitivity and positional accuracy of the new instruments also allowed more distant, compact, or reddened open clusters to be studied, thus enabling exploration of the X-ray source populations over a broader range of cluster parameter space. So far, especially the addition of the old (8 Gyr), massive cluster NGC 6791 (van den Berg et al. 2012) has been useful for gaining new insights thanks to the many X-ray sources detected and the extensive body of available optical data (deep photometry, proper motions, variability, follow-up spectroscopy). There are now two parallel ongoing efforts aimed at studying the X-ray properties of old and intermediate-age open clusters. The *Chandra* survey by van den Berg et al. focuses on the oldest clusters ($\gtrsim$ 3 Gyr) while the survey by Pooley et al. with *XMM-Newton* also includes several younger ones.

Chandra and *XMM-Newton* observations have not (yet) led to the discovery of any fundamentally different source classes than those already found with *ROSAT*, although, if validated by follow-up spectroscopy, the candidate quiescent low-mass X-ray binary (qLMXB) in NGC 6819 reported by Gosnell et al. (2012) could turn out to be the first of its kind to be uncovered in an open cluster (Sect. 3.5). However, the much-improved positional accuracy has significantly reduced the chances for spurious identifications, and the broader spectral response has facilitated source classification.

3. X-ray source classes

3.1. Cataclysmic variables

After the discovery of EU Cnc in M 67, four more open-cluster CVs were found, all in NGC 6791 (Kaluzny et al. 1997; van den Berg et al. 2012). EU Cnc is quite faint ($\sim 4\times10^{29}$ erg s^{-1}, 0.3–7 keV), while B 8 in NGC 6791 is two orders of magnitude brighter. Most were first identified as CV candidates through their optical colors or variability, while CX 19 in NGC 6791 is the first X-ray–selected CV in an open cluster. Its proposed optical counterpart was chosen as a high-priority target for follow-up spectroscopy based on the blue color; Balmer and He II emission lines confirm its CV nature. For CVs in globular clusters it is a point of discussion as to whether they have intrinsically different properties than those in the field. The on-average larger X-ray luminosities, higher X-ray–to–optical flux ratios, and possibly lower outburst rates for globular-cluster CVs could perhaps be explained if there is a prevalence of magnetic systems among them, or if the typical accretion rates are lower (Edmonds et al. 2003). These differences could then be related to their formation scenarios, which may have involved dynamical interactions. As there are only a handful of confirmed CVs in open clusters, it is difficult to make a comparison with either the field or globular-cluster CV population. Besides EU Cnc, CX 19 is possibly magnetic (van den Berg et al. 2012), which is in line with the finding that many field CVs that turn out to be magnetic are

bright in X-rays and are first discovered in X-rays. What can be said is that scaling the number of CVs in NGC 6791 by cluster mass results in a CV density that is consistent with estimates for the CV density in the field, which points at a primordial origin and does not require any dynamical formation or destruction processes.

If the density of CVs in open clusters is indeed similar as in the field, the reason why some CV searches have not been successful is likely because of the relatively small number of cluster members surveyed (e.g. Kafka et al. 2004). A few candidate CVs in open clusters have been identified through dwarf-nova–like outbursts (V 57 in in the 2–3 Gyr old NGC 2158, Mochejska et al. (2006); 15877_2 in the ~3.5 Gyr old NGC 6253 de Marchi et al. (2010)), or their X-ray spectral properties and UV/optical colors (X 2 in NGC 6819, Gosnell et al. 2012). More follow-up is needed to establish the nature and membership status of these candidates. Some of the faint, blue candidate counterparts to *Chandra* or *XMM-Newton* sources may also turn out to be CVs (or other compact accreting binaries), although, at least for those in M 67 and NGC 6791, it is estimated that they are mainly background galaxies.

3.2. Active binaries

Active binaries, including both detached systems and contact binaries, are the most common open-cluster X-ray sources. They are among the brightest sources, but found down to the detection limit of the observations ($\sim 2\times10^{28}$ erg s^{-1}, 0.3–7 keV, for M 67). The study of coronal activity of M 67 sources by Pasquini & Belloni (1998) found no relation between the *ROSAT* X-ray luminosity and stellar parameters like optical magnitude or orbital period. As we now know, this was the result of wrong or incomplete information on orbital or rotation periods, by the inclusion of sources with likely more complex evolutionary histories than regular ABs, and by the high limiting flux of the initial *ROSAT* pointing (which, as it turns out, was only sensitive enough to detect regular ABs with orbital periods between ~0.5 and 1.5 d). Later studies with larger, and cleaner, AB samples *do* reveal an activity-rotation relationship in the sense that the coronal X-ray luminosity decreases as a function of orbital period up to the limiting period for tidal circularization (van den Berg et al. 2004, 2012); for M 67 this period lies around 12 d. The explanation is that the stellar rotation, and hence the level of activity, is lower in tidally-circularized (and thus synchronized) binaries with longer periods. As is seen for the X-ray emission of single stars (e.g. Randich 1997), saturation of the X-ray activity occurs for stars in binaries with the shortest orbital periods and highest rotation rates, such as contact binaries. Since the time scale for tidal synchronization is shorter than for circularization, it is possible that the rotation of stars in eccentric binaries is locked to the orbital period around periastron where the interaction is strongest (so-called pseudo-synchronization). If the resulting rotation is fast enough to generate activity, such binaries can also show up as ABs. An example is the ~32-d period binary S 1242 in M 67, which has an eccentricity of 0.66 and whose photometric period of 4.88 d (Gilliland et al. 1991) corresponds to the corotation period at periastron.

van den Berg et al. (2012) compared the number of ABs inside the half-mass radius with $L_X \gtrsim 1\times10^{30}$ erg s^{-1} (0.3–7 keV) for three old open clusters that were observed with *Chandra* or *XMM-Newton*. Surprisingly, they find that this number does not scale with cluster mass, as would be expected for a primordial population. NGC 6791 is 4.5–6.4 times more massive than M 67, but has 0.9–1.6 times the number of ABs. NGC 6819 has 2.4 times the mass of M 67, but only has a fraction (~0.13) of the number of ABs. At this point we have no explanation for this, and (deeper) studies of more

clusters are required. Possibly, M 67 has lost a higher fraction of its initial mass compared to the other two clusters. If it lost preferentially single, low-mass stars through evaporation while retaining more binary stars that sunk to the core due to mass segregation, the current binary population would appear as representative of a much more massive cluster. The small number of X-ray sources in NGC 188 could therefore not just be the result of limited sensitivity of the *ROSAT* pointing, as was suggested by Verbunt (2000).

3.3. Sub-subgiants

Among the brightest (up to $\sim 10^{31}$ erg s^{-1}, 0.3–7 keV) X-ray sources in old open clusters are binaries that lie below or to the red of the sub-giant branch, the so-called sub-subgiants or red stragglers. This name derives from the fact that their photometry cannot be explained by the combined light of two ordinary cluster members. Over a dozen sub-subgiants are known in open and globular clusters, and they are typically detected in X-rays. All show signs of binarity, but they include very distinct source classes (detached binaries, CVs, and at least one neutron star with an evolved companion). It is possible that they exist in the field as well, but the poorly constrained ages and distances of field stars make it difficult to recognize them as sub-subgiants.

Given their X-ray spectral properties and signs of chromospheric activity (Ca II H&K and Hα emission), the X-ray emission of sub-subgiants in old open clusters is likely the result of coronal activity. This explanation is not without problems for all systems, though. While the optical variability of the sub-subgiant S 1113 in M 67 suggests that the rotation is synchronized to the orbit (van den Berg et al. 2002), the light curve of the other M 67 sub-subgiant S 1063 (an eccentric binary in a 18.4-d period) displays what looks like spot modulation on a period that is longer than both the pseudo-synchronous and orbital period (Fig. 2). Tidal locking, which sets the stellar rotation in normal ABs, may not have been achieved yet, or another mechanism drives the spin rate in S 1063. A recent or ongoing episode of mass transfer has been invoked to explain the optical photometry of CVs in 47 Tuc that lie in the sub-subgiant region of the color-magnitude diagram (Albrow et al. 2001). But for S 1063 the eccentric orbit argues against mass transfer in the recent past, as a (nearly) Roche-lobe filling star would have quickly circularized the orbit (Mathieu et al. 2003).

Sub-subgiants are not uncommon in old open clusters, and their numbers appear to scale with cluster mass (van den Berg et al. 2012, see also Table 1). This suggests that the explanation of their anomalous properties lies in a hitherto overlooked binary-evolution path, and is not the result of a short-lived perturbed state. N-body simulations by Hurley et al. (2005) created one star below the sub-giant branch, which resulted from the merger of two stars in a binary after instable mass transfer. This star is single though, and some basic ingredient (primordial triples?) is still missing from the models.

3.4. Long-period binaries, and blue and yellow stragglers

Another class of poorly-understood X-ray sources are those that are identified with wide binaries. In such systems tidal interaction is far too weak to lead to enhanced stellar rotation rates. In most cases the suggested optical counterparts also have anomalous optical properties: based on their photometry they are classified as blue or yellow stragglers, which is a sign of a complex past that may have involved mass transfer, a merger, or perhaps some kind of dynamical encounter. It is not clear if their X-ray emission is always intrinsically linked to their evolutionary histories. An example of a

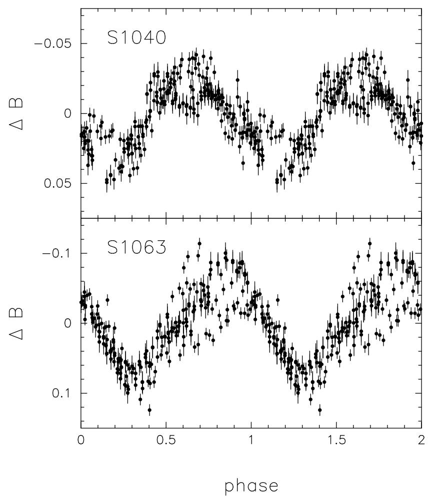

Figure 2 YALO light curves from 2001 Oct to 2003 Jun of the yellow-straggler and sub-subgiant binaries S 1040 (*top*) and S 1063 (*bottom*) in M 67. For S 1040 the data are folded on a period of 47.05 d, for S 1063 on 23.38 d. For both, photometric variability is likely caused by spots near active regions on the surface. The modulation periods are longer than the orbital periods and, for S 1063, also longer than the pseudo-synchronous rotation period. This suggests that the rotation is not synchronized, and therefore that it is not (only) tidal coupling that is responsible for the enhanced magnetic activity.

wide spectroscopic binary with "normal" colors is the *ROSAT* source #6 (VR 111) in NGC 6940, which has a period of almost 3600 d (Belloni & Tagliaferri 1997).

Blue stragglers are found in most old clusters, and it is a matter of debate if they are formed through binary evolution, dynamical encounters, or both (see e.g. Mathieu & Geller 2009). X-ray emission is not a common property of blue stragglers. As the X-rays indicate that some kind of binary interaction is currently active, tracking down their origin can also provide clues to what led to a system's formation. The best example is S 1082 in M 67. Studies triggered by its X-ray detection showed that it contains two stars that are blue stragglers on their own account, and that a close and wide binary contribute to the optical light (van den Berg et al. 2001; Sandquist et al. 2003). If these are bound, at least six stars must have been involved in creating S 1082, making a dynamical formation most likely (Leigh & Sills 2011). Other X-ray–emitting blue stragglers in wide orbits are S 997 in M 67 (van den Berg et al. 2004), H 209 in NGC 752 (Sect. 2.1), and possibly L 44 in IC 4651 (Belloni & Tagliaferri 1998).

M 67 features three yellow stragglers, i.e. stars between the blue stragglers and the red-giant branch, which all have wide orbits ($\gtrsim$40 d) and secure *Chandra* detections. The eccentric binaries S 1072 and S 1237 show no signs of chromospheric activity (van den Berg et al. 1999); possibly a faint close binary in these systems is overwhelmed by the light of the primary. S 1040 is an interesting system for which Verbunt & Phinney (1995) predicted the presence of a white-dwarf secondary based on the circular, 42.8-d orbit. They argued that the radius of the yellow-straggler primary is too small to be responsible for the circularization, which must then be attributed to a former primary that was much larger in the past and filled its Roche lobe. The white dwarf was indeed discovered in a UV pointing of M 67 (Landsman et al. 1997). Magnetic activity of the yellow straggler is manifested in the coronal X-ray emission, but also in chromospheric emission lines (e.g. van den Berg et al. 1999), and is possibly a relic of the previous phase of mass transfer. The rotation rate as derived from photometric variability is lower than expected for synchronous rotation (see Fig. 2).

3.5. Other source classes

Continued loss of angular momentum in a contact binary can lead to a merger of the two stars. It is expected that the result is a single, rapidly-rotating star. The brightest ($\sim 2\times10^{31}$ erg s^{-1}, 0.1–2.4 keV) *ROSAT* source X 29 in NGC 188 was identified with such an FK Com-type giant (Belloni et al. 1998). As the X-rays are driven by rotation, this class of coronal emitter is closely related to the ABs.

A few X-rays sources have been identified with cluster giants that show no signs of binarity. Some are among the brightest sources in the cluster. Examples are the *ROSAT* sources #13 (VR 108) in NGC 6940 (Belloni & Tagliaferri 1997) and X 19 (S 364) in M 67 (Belloni et al. 1998), and the *Chandra* source CX 9 in NGC6791 (van den Berg et al. 2012). These could be truly single stars or very wide binaries; in both cases the X-rays remain a mystery. Alternatively, these stars could be spurious matches (although VR 108 does show weak signs of Ca II H&K activity; van den Berg & Verbunt (2001)).

Optical spectroscopy of the faint blue counterpart to a very soft *ROSAT* source revealed it to be a hot white dwarf (Pasquini et al. 1994). There are no indications for binarity of this star, and given the estimated temperature of about 68 000 K (Fleming et al. 1997) it is most likely a thermal X-ray emitter. While Pasquini et al. argue that it is a member because single X-ray–emitting white dwarfs are rare, the proper-motion study by Yadav et al. (2008) suggests a low probability for cluster membership.

Based on its soft X-ray spectrum and limits on the X-ray–to–optical flux ratio, Gosnell et al. (2012) tentatively classify the brightest X-ray source detected in the field of NGC 6819 as a qLMXBs. As the chances of finding any primordial LMXBs in a cluster the size of NGC 6819 are low, they suggest that—if its qLMXB nature is confirmed—this object likely has a dynamical origin. So far, no qLMXBs have been found in open clusters. van den Berg et al. (2004) suggested that the soft and highly variable X-ray source CX 2 in M 67 could be a good candidate, but follow-up spectroscopy showed that the candidate optical counterpart is an active galaxy.

4. Comparison with globular clusters

It has been known for a long time that as a result of their high central stellar densities, globular clusters are very efficient in forming objects that are rare in the field such as LMXBS and their descendants, the milli-second pulsars or MSPs (see the contribution by Frank Verbunt). Verbunt (2000) pointed out first that, when bright ($\gtrsim 10^{36}$ erg s^{-1}) LMXBs in globular clusters are disregarded, the integrated *ROSAT* X-ray luminosities per unit mass of most globular clusters is lower than that of M 67. This raised the questions of whether globular clusters are efficient at destroying those binaries that are responsible for most of the X-ray emission in old open clusters (i.e. ABs in the case of M 67), or whether M 67 contains an exceptionally high fraction of ABs. At the time, this problem could not be tackled directly by observations because of the lack of sensitivity and spatial resolution to detect and identify ABs in globular clusters.

With the excellent imaging capabilities of *Chandra* we can revisit this issue. Although almost 80 globular clusters have been studied with *Chandra*, only a handful have been observed with sufficient sensitivity to access a significant part of the AB X-ray luminosity function. van den Berg et al. (2012) made a detailed comparison between the numbers of CVs, ABs, and sub-subgiants down to $L_X = 1 \times 10^{30}$ erg s^{-1} in those old open and globular clusters for which the most comprehensive source clas-

cluster	age (Gyr)	M ($M_\odot$)	N_X	$N_{X,CV}$	$N_{X,S}$	$N_{X,AB}$	log(2 L_{30}/M)
NGC 6819	2–2.4	2600	*6–7*	*1?*	*1?*	*1?*	...
M 67	4	1100	12	0	1	7–8	28.9
NGC 6791	8	(5–7)$\times 10^3$	15–19	3–4	3	7–11	28.6–28.8
47 Tuc	11.2	1.3×10^6	~200	30–119	10	42–131	28.0
NGC 6397	13.9	2.5×10^5	15–18	11	2	0–2	27.7

Table 1. X-ray sources in globular and old open clusters inside the half-mass radius r_h with $L_X \gtrsim 1 \times 10^{30}$ erg s^{-1} in the 0.3–7 keV band. I list the number of sources identified with cluster members (N_X), CVs ($N_{X,CV}$), sub-subgiants ($N_{X,S}$), and ABs ($N_{X,AB}$). The numbers for NGC 6819 are uncertain due to limited optical follow up. Log (2 L_{30}/M) is, in log units, the ratio of the total X-ray luminosity of the N_X sources to the cluster mass (M) divided by two to account for the selection of sources inside r_h. The horizontal line separates open and globular clusters. Main references: Gosnell et al. (2012), van den Berg et al. (2004, 2012), Cohn et al. (2010), Heinke et al. (2005). See van den Berg et al. (2012) for details.

sifications are available (see also Table 1). It turns out that both suggested scenarios appear to be relevant for explaining the integrated X-ray properties of old clusters. As discussed in Sec. 3.2, among old open clusters M 67 has a high AB frequency for its mass. On the other hand, not just M 67 but also NGC 6791 has a higher X-ray emissivity than the two globular clusters. All three main source classes are under-represented in globulars when scaling by mass. The specific frequency of CVs appears to be less disparate than that of ABs; a possible reason is that in globulars they are dynamically created as well (Pooley & Hut 2006). The X-ray emission from qLMXBs and MSPs in globular clusters, i.e. types of faint X-ray sources of which there are no confirmed cases in old open clusters, cannot make up for the lack of CVs and coronal sources. In a study of a larger sample of globular clusters, Heinke et al. (in preparation) find that their X-ray emissivity is lower than that of old low-density environments in general.

The suppressed numbers of CVs and ABs is in line with the overall low binary frequency in globular clusters compared to open clusters (Milone et al. 2012). This suggests that in the intricate process of forming and breaking up binaries in the cores of globulars, the balance is tipped in favor of binary destruction—not just for wide systems but also for close, interacting binaries that dominate the X-ray emission of old populations. Much remains to be done to classify, dissect, and compare the populations of faint X-ray sources in different settings in more detail. Old open clusters, with their rich X-ray source populations that are relatively accessible for optical follow-up work, can play a crucial part in these studies.

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